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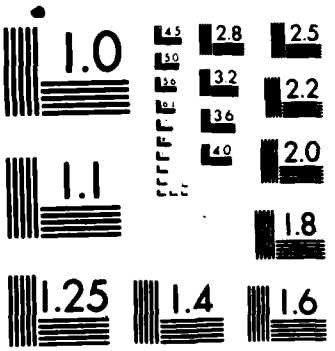

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First application of extended x-ray absorption fine structure (EXAFS) technique to measurements of interatomic distance, local order, and strain in semiconductor superlattices and heterostructures has been successfully demonstrated. This result opens many possibilities for obtaining unique structural information in various semiconductors.

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# Annual Letter Report

(For the period Aug. 1, 1984 to July 31, 1985)

Contract Number: N00014-83-K-0675

Title: X-ray Absorption Fine Structure Studies of Semiconductor Superlattices

Principal Investigator: Yi-Han Kao

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For the period from August 1, 1984 to July 31, 1985, the present project enters its second year of research. Our main goal is the first application of the extended x-ray absorption fine structure (EXAFS) technique to the measurement of microscopic structure in semiconductor superlattices. Due to the lack of long range order in the growth direction, as well as the presence of several different atomic species in this class of modulated-structure semiconductors, the conventional diffraction technique is not very useful for probing the local structural properties. .On the other hand, the EXAFS technique offers element selectivity and is more sensitive to short range order, it can therefore be used to obtain some unique information about the superlattices and heterostructures. Our experimental results have successfully demonstrated, for the first time, that such an approach is indeed possible, and we have already obtained valuable structural information about InAs-AℓSb superlattices, $In_xGa_{1-x}As$/InP heterostructures grown by MBE and LPE methods, and InAs/GaAs heterojunctions.

The InAs-AℓSb superlattices were prepared at IBM by our collaborator Dr. Leroy L. Chang using the MBE technique. The EXAFS experiments were performed at the Cornell High Energy Synchrotron Source (CHESS). Our results have provided the first measurement of the In-As interatomic distance in the growth direction and local order in the InAs layers. By using the highly polarized beam from synchrotron radiation, we have determined a 20% anisotropy in the electron mean free path in the InAs films. For the $In_xGa_{1-x}As$/InP heterostructures, we have shown that EXAFS spectra can be used for structural as well as chemical characterization. In particular, we have found that Vegard's law is not valid in these heterostructures. For the InAs/GaAs heterojunctions, our EXAFS results provide the first direct measurement of strain in an InAs 50 Å thin film as a consequence of lattice mismatch between InAs and GaAs.

This suggests a very useful method to determine the lattice strain in strained-layer superlattices, an area of considerable recent interest for the development of new superlattice materials and electronic devices.

Our research work on the application of EXAFS to semiconductor studies has also attracted attention of the industry. The same method we used to investigate superlattice structures can also be employed to study impurities in semiconductors. Both IBM and Philips Laboratories have shown interest in using the EXAFS techniques for studying various semiconductors directly related to device applications. Joint experiments are already underway. This indicates that ONR-sponsored university research has shown an impact on industrial developments.

The results obtained in the past are more of an exploratory nature which are of course important for confirming the feasibility of applying a new technique to material studies. Now that we have successfully demonstrated the usefulness of the EXAFS technique in semiconductor research, our plan for the immediate future is to carry out systematic measurements of lattice strain as a function of film thickness in some heterostructure. It will be very interesting to correlate the measured strain with changes in band structure in a series of strained-layer superlattice. A set of InAs/GaAs samples has already been made by our IBM collaborator. EXAFS measurements of these samples will begin in the near future as soon as we get a scheduled beamtime for synchrotron radiation.

List of Publications

83-K-0675-1 "Extended X-ray Absorption Fine Structure Studies of Diffused Copper Impurities in ZnSe", A.I. Goldman, E. Canova, Y.H. Kao, B.J. Fitzpatrick, R.N. Bhargava, and J.C. Phillips, Appl. Phys. Lett. 43, 836 (1983).

83-K-0675-2 "EXAFS Studies of the Local Environment Surrounding Ge in $Nb_3Ge_xAl_{1-x}$ Superconducting Alloys", A.I. Goldman, E. Canova, and Y.H. Kao, Bull. Am. Phys. Soc. 29, 385 (1984). (An expanded paper is being prepared for publication).

83-K-0675-3 "EXAFS Study of Yttria Stabilized Zirconia" (with E. Canova, A.I. Goldman, W.L. Roth, and R. Wong), Proceedings of Third International EXAFS Conference (1984), p.442.

83-K-0675-4 "Applications of EXAFS in Semiconductor Research", Proc. 1984 International Electronic Devices and Materials Symposium (1984), p. 553 (Invited talk).

83-K-0675-5 "Interatomic Distance and Local Order in InAs-AlSb Semiconductor Superlattices" (with E. Canova, A.I. Goldman, S. Woronick, and L.L. Chang), Phys. Rev. B31, 8308 (1985).

83-K-0675-6 "Studies of Return Maps, Chaos and Phase-Locked States" (with D.R. He and W.J. Yeh), Phys. Rev. B31, 1359 (1985).

83-K-0675-7 "Universal Scaling and Chaotic Behavior", Proc. IC SQUID '85 (Berlin, 1985) (Invited talk), in press.

83-K-0675-8 "Probing the Structure of Semiconductor Superlattices and Heterostructures by EXAFS" (with S.C. Woronick, E. Canova, G.W. Su, and L.L. Chang), Proceedings of 2nd International Conference on Modulated Semiconductor Structures (Kyoto, 1985), in press.

83-K-0675-9 "Soft X-ray Spectroscopy with a Scintillation Detector" (with B.X. Yang, J. Kirz, and T.K. Sham), Proceedings of International Conference on X-ray and VUV Synchrotron Radiation Instrumentation (Stanford, 1985), in press.

83-K-0675-10 "EXAFS Studies of Ion Implanted Bismuth" (with E.M. Kunoff and M.S. Dresselhaus), Proceedings of Materials Research Society, Symposium K (1984), in press.

83-K-0675-11 "Transmission Measurements of Soft X-ray Absorption Fine Structure in Solid by a New Scintillation Technique" (with B.X. Yang, J. Kirz, C.X. Gu, R.N. Bhargava, D.A. Cammack, and R.J. Dalby), Phys. Lett. A, in press.

Personnel working on the present project:

Y.H. Kao - Principal Investigator
Professor of Physics

A.I. Goldman - Graduate student. Ph.D. degree awarded May, 1984
Worked as a postdoc till September 1984.

G.W. Su - Postdoc
November, 1984 - present

E. Canova - graduate student

S.C. Woronick - graduate student

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